Liming and Twenty Years of Litter Raking and Burning under Red (and White) Pine[1]

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CHARACTERISTIC of most forests, particularly in the northern latitude, is the deposition of organic debris known as forest floor. The nature of this deposition and its role in the life of the stand has been the subject of many investigations over the past 75 years, chiefly in western Europe. The practice of litter removal for bedding, common in parts of Europe, has been found in many instances to be detrimental to the soil and the stand (12, 14). Where the soil is heavier and quite fertile no such effect was in evidence (14). Likewise, removal by burning has been reported to have a deleterious effect (3, 15), but the findings by various investigators are by no means in agreement on the matter (1, 5).

To determine what might be expected when such practices are followed on typical sandy soil in Connecticut, an experiment was initiated in 1929 (as one of the first research projects on forest soils in the Northeast) on a Station-owned plantation. At that time there was very little in American literature on the subject. The primary questions needing answers were: (a) how much litter had accumulated over the 27 years of the stand's existence? (b) how much litter was being deposited annually? (c) what happens to the soil and the stand

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TABLE 1.—*Principal physical and chemical properties of the soil under the plantation.*

A horizon (A_{11}, A_{12},) of Merrimac loamy sand			
	%		
Total sands	88.1	pH	4.7
Fine sand	26.1	Total N	% 0.05
Silt	5.4	Organic carbon	% 1.75
Clay	5.5	C:N	34
Moisture equivalent	7.6	Available P ppm	12
		Base capacity mg. eq.*	5.0

* Milligram equivalent per 100 g of oven dry soil.

when the litter is raked or burned off each year? (d) considering the acid character of the litter and soil, what would be the effect of liming?

DESCRIPTION OF THE PLANTATION AND SOIL

This tract of land, formerly known as the Rainbow Forest Plantation, is located in the Connecticut Valley some 13 miles north of Hartford. Previously used for growing corn and tobacco, and abandoned because of its low productive capacity (6), the land was acquired by the Experiment Station in 1900–1905 and planted to various species to determine their suitability for reforesting land of this character. Reversion following abandonment had not progressed beyond the broomsedge (*Andropogon*) stage at the time of purchase.

The studies herein reported were confined to plots (hereinafter referred to as blocks) 22 and 25. Block 22 was planted in 1902 to 4-year red pine (*Pinus resinosa* Solander) transplants on a 4½ by 5 foot spacing. Block 25 was planted the same year to eastern white pine (*P. Strobus* L.) seedlings 8 to 18 inches tall, which had been collected in an adjoining town. These were spaced 4½ by 5½ feet. Owing to a moderately heavy mortality, to differences in the planting stock, and to weevil injury, the stand became irregular and acquired the appearance of a natural stand which had seeded in over a period of years.

The soil in both blocks is Merrimac loamy sand, a level terrace of glacio-fluvial origin. The general profile description is as follows:

Ao	1½ in. (¾–2½ in. range)—Old Field or Imperfect Mor consisting of an L (litter) layer of variable thickness depending on time of year examined; a rather thin and poorly developed F layer; and a trace of a very dark brown to black amorphous H layer.[3]
A_{11}	0–1 in.—Grayish brown (10 YR 5/2) loamy sand.[4]
A_{12}	1–8 in.—Brown (10 YR 5/3) loamy sand (a former plow layer).
B_{21}	8–19 in.—Yellowish brown (10 YR 5/6) sand to loamy sand.
B_{22}	19–27 in.—Light yellowish brown (10 YR 6/4) sand to coarse sand.
C_1	27 in. plus—Light brownish gray (10 YR 6/2) to light yellowish brown (10 YR 6/4) coarse sand and fine gravel.

The substratum below the C horizon consists of strata of sand and gravel of variable thickness and coarseness.

Table 1 shows that the soil is a typical acid, loamy sand of low fertility. Measurements of another plot in the same block indicated a site index of 8 feet.[5]

Annual precipitation averages 42.2 inches, usually well distributed throughout the year, but with occasional prolonged dry periods. The mean January temperature is 27.6° F with extremes of —16 and 70 reported. The mean July temperature is 72.9, with minimum and maximum ranges of 48 and 101 respectively.[6]

PROCEDURE

In the spring of 1929 seven 1/40-acre plots were laid out in the red pine block, and six in the white pine block. All plots were given an initial light thinning to relieve competition and create a more even canopy, the cut material being removed from the plots.

The trees were numbered, and each was very carefully measured for total height (as of the fall of 1928) and d.b.h. (diameter at breast height, i.e., 4½ feet). Heights were also measured as of the fall of 1923. Subsequent tree measurements were obtained in the fall of 1934 and spring of 1948 (i.e., heights as of fall of 1947). There was a second light thinning in 1934.

The plot treatments (which included the narrow borders around each plot) were as follows:

Plot numbers		
Red pine	**White pine**	**Treatments**
1	12	Raked annually
2	9	Raked annually and limed
3	11	Check (no treatment)
4	8	Check plus lime
5	10	Burned annually
6	7	Burned annually and limed
13	--	Triple Ao (litter from plots 1 and 2 applied to this plot initially and annually)

In the initial and all subsequent rakings, all material was removed down to the mineral soil. This was also the goal in burning but it was not always fully achieved. The initial burning was particularly difficult and required a fluffing up of the lower layers of the forest floor and several repeat burns. Even a blow torch was resorted to in especially stubborn cases. Usually the subsequent annual burns were satisfactory.

The lime treatment consisted of 100 pounds of ground calcic limestone per plot (approximately 4,000 pounds per acre) applied in 1929 to plots 2, 4, 6, 7, 8, and 9, after the initial raking or burning of the forest floor on those plots receiving such treatment. A second application was made in 1930, using 100 pounds on each of plots 2, 6, 7, and 9, and 50 pounds on plots 4 and 8.

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[3] Where the several horizons of the forest floor are more clearly developed than they are here, the Ao is separated into Aoo = L, A_{01} = F, A_{02} = H.

[4] Approximate color of moist soil according to the Committee Report on Soil Color, Soil Survey Division, B. P. I. S. A. E., U. S. D. A., Beltsville, Md., mimeographed.

[5] Height in feet at 15 years from seed (as described in Conn. Sta. Bul. 330, 1931). Unpublished data on red pine permanent sample plots.

[6] Climatological data for Hartford, Conn., based on 44 years weather records of the Weather Bureau, U. S. Department of Commerce, supplied by the Tobacco Laboratory of this Station located at Windsor.

Soil studies included the following: Ascertainment of the amount of forest floor initially present by cutting out and weighing three or four 1-foot squares per plot, and the annual deposition by weighing the entire amount obtained on the raked plots; soil moisture by oven-drying at 105° C; pH by either quinhydrone or glass electrode pH meter; ammonia and nitrate nitrogen at intervals during the first 7 years, using the usual laboratory methods of analysis; and a rather thorough sampling, with subsequent physical and chemical tests,[7] in 1939 and 1944. A few measurements of undisturbed litter were obtained in 1950.

Unfortunately the white pine stand was lost in the 1938 hurricane, with no possibility of final measurements, and a number of red pines, chiefly in plots 2, 4 and 13, were tilted by the wind and had to be straightened with guy wires. Although the treatments were not replicated, the uniformity of the soil, topography, and stand, and the number of trees (20–36) measured on each plot lend validity to the findings. They are indicative of what may be expected to take place in other locations where soil and climate are similar to that at the Rainbow Plantation.

RESULTS

SOIL STUDIES

WEIGHT OF FOREST FLOOR AND ANNUAL LITTER DEPOSITION

Measurements on litter quantity under red pine are given in Table 2. The amounts initially present on plots 1 and 2, chosen for raking, were identical and were considerably lower than the average of the 6 plots. The annual needle fall varied from year to year, depending on weather conditions (maximum variation 1,640 to 5,500 pounds per acre), but the averages for each 5-year period show a general increase in amount.

That the net rate of accumulation was relatively slow is shown by the following computations (all data in pounds per acre):

	Plot 3	Plot 4	Plot 13
Initially present in summer of 1929	32,746	25,928	27,800 [8]
Added in 21 years of natural needle fall based on rakings in plots 1 and 2 (21×3,555)	74,655	74,655	74,655
Added from plots 1 and 2 in 18 years [9]	none	none	127,980
	107,401	100,583	230,435
Present in summer of 1950 [10]	38,156	30,377	63,956
Decomposed in 21 years	69,245	70,206	166,479
Average decomposition per year	3,297	3,343	7,927
Net gain in forest floor per year, average (1950–1929/21)	258	212	1,722

Thus in plots 3 and 4, although there was an estimated average natural increase of 3,555 pounds per year, about 3,300 pounds were lost by decomposition, leaving an annual net gain of less than 300 pounds per year. In the case of Triple Ao plot 13 where the estimated annual increment of 3,555 pounds was supplemented with twice that quantity from the two raked plots, the rate of decomposition was high (7,927 pounds), leaving an average net gain of 1,722 pounds per year.

On the white pine plots the quantity of debris constituting the forest floor in 1929 averaged 21,539 pounds per acre (S.D. 6,511 pounds). However, the annual increment as determined by raking, based on 4 years' data (1934–37), averaging 3,571 pounds, which was about 21% greater than that for red pine for the same period.

COMPOSITION OF THE LITTER

The analysis of raked litter collected in 1935 was as follows in per cent of dry matter:

	Ash	N	P	Ca	SiO_2
Red pine, unlimed (plot 1)	3.4	0.49	0.056	0.45	0.80
Red pine, limed (plot 2)	4.2	.46	.051	.76	1.37
White pine, unlimed (plot 12)	6.9	.57	.073	.47	3.66
White pine, limed (plot 9)	6.5	.74	.077	.78	3.20

The chief items of interest are (a) the marked effect of lime on the Ca content, and (b) the difference between red pine and white pine litter in ash, N, P, and SiO_2 content.

SOIL MOISTURE OF THE A HORIZON

During the first few years soil moisture determinations of that portion of the profile most likely to be influenced by the treatments—the upper 4 or 5 inches—were made at intervals during the growing season, usually toward the end of dry periods. There was considerable lack of consistence in the results and for that reason the data are not presented in detail. Certain trends were in evidence, however. First, the soil on the raked and burned plots tended to run slightly lower in

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[7] Moisture equivalent by the method of Veihmeyer *et al.*, *Proc. First Int. Cong. Soil Sci.*, Washington, D. C., 1:512–534, 1927. Water-holding capacity and bulk density on 250-ml cores of soil; total N by one of the standard methods; organic C by the Parr method (A. O. A. C. *Methods of Analysis*, pp. 25–26, 1925, and *Ind. and Eng. Chem. Anal. Ed.*, 1:145–148, 1929); available P by the Truog method (Jour. Amer. Soc. Agron., 22:874–882, 1930); exchangeable Ca on N/1 ammonium acetate extraction; exchangeable H and cation exchange capacity by a procedure (*Soil Sci. Soc. Amer. Proc.* (1940), 5:344–349, 1941) based on that of Chandler (*Jour. Agr. Res.*, 59:491–506, 1939).

[8] Average of other six plots; assumed to be approximately correct for plot 13.

[9] Litter from plots 1 and 2 was placed on plot 13 on only 18 years out of the 21 involved. (2 plots × 3,555 pounds × 18 years = 127,980 pounds)

[10] Although the experiment was terminated in 1948 the plots were still in existence and undisturbed in 1950.

TABLE 2.—*Amount of litter under red pine, pounds per acre.*

	Treatments							
	Check	Check + lime	Raked	Raked + lime	Burned	Burned + lime	Triple Ao (3×Ao)	Average
Amount initially present in 1929	32,746	25,928	21,030	21,030	32,074	34,186	———	27,800*
Average annual deposition								
1931–35	———†	———	3,065	2,722	———	———	———	2,893
1936–40	———	———	3,939	3,583	———	———	———	3,761
1941–44, 46	———	———	4,183	3,836	———	———	———	4,010
Average								3,555
Amount present in 1950‡	38,156	30,377	———	———	———	———	63,956	
Increase over 1929	5,410	4,449	———	———	———	———	36,156§	

* Standard deviation of the mean: 5,972 pounds.
† Annual deposition not determined on plots 3, 4, 5, 6, and 13.
‡ Although the experiment was terminated in 1948, the plots were still in existence and undisturbed in 1950.
§ Assuming the average, 27,800, as the amount present in 1929. The litter from plots 1 and 2 was placed on plot 13 for 18 consecutive years.

TABLE 3.—*Nitrogen transformation during a 3½-month incubation period, June 19–Oct. 1. Gain or loss in parts per million.*

Horizon	Red pine plots							White pine plots					
	Check	Ck+L	Raked	R+L	Burned	B+L	3×Ao	Check	Ck+L	Raked	R+L	Burned	B+L
							Ammonia Nitrogen						
Ao	0	0	—	—	—	—	80*	38	26	—	—	—	—
A_{11}	137*	13	9	—1	19	—1	0	15	18	16	2	19	0
A_{12}	13	3	0	—2	0	0	—	0	16	—4	12	0	2
							Nitrate Nitrogen						
Ao	1	20	—	—	—	—	1	1	67	—	—	—	—
A_{11}	1	13	1	8	0	30	0	5	33	2	46	2	17
A_{12}	1	1	1	2	0	10	—	2	12	2	5	1	0

* These unusually high gains are out of line and are probably erratic.

moisture than the checks, and the triple Ao plots slightly higher, as shown by the mean values on unlimed plots, in per cent of dry weight:

	Check	Raked	Burned	3 × Ao
Red pine	5.4	5.0	4.5	5.9
White pine	7.3	5.4	6.9	--

These differences were much less than had been anticipated.

Second, under red pine the limed plots were consistently higher in moisture than the unlimed, although the differences are small as seen by the following mean values:

	Check	Raked	Burned
No lime[11]	5.7	5.5	4.7
Limed	6.3	6.7	5.8

Under white pine, on the other hand, the effects of lime were not consistent.

CHARACTERISTICS OF THE SOIL AS AFFECTED BY TREATMENT

Only the more pertinent data will be presented. Where the effects were slight or nil, they will be dismissed with a brief statement.

(a) **Moisture equivalent** was essentially unaffected. This is in agreement with the findings of Alway and Rost (1) on land that had been subjected to a severe burn.

(b) **Water-holding capacity** of the upper 2½ inches of mineral soil was slightly higher on the limed plots. Otherwise there were no differences.

(c) **Bulk density** differences were negligible.

(d) **Reaction (pH)** values of the Ao and A_{11} horizons, shown in Figs. 1 and 2, and Table 4, indicate first, that where lime had been applied to undisturbed litter (check plus lime), its greatest effect was on the litter (Ao) layer (graph line 2, Figs. 1 and 2), which effect gradually diminished with time; second, that lime so applied raised the pH of the underlying A_{11} horizon (cf. graph lines 7 and 4) but to a lesser degree than where the litter had first been removed (cf. lines 7 and 8); and third, that burning raised the pH of the A_{11}, whether or not lime was used (cf. lines 6 and 9), and this difference

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[11] The discrepancies between these values and those for red pine in the previous tabulation are due to differences in sampling dates.

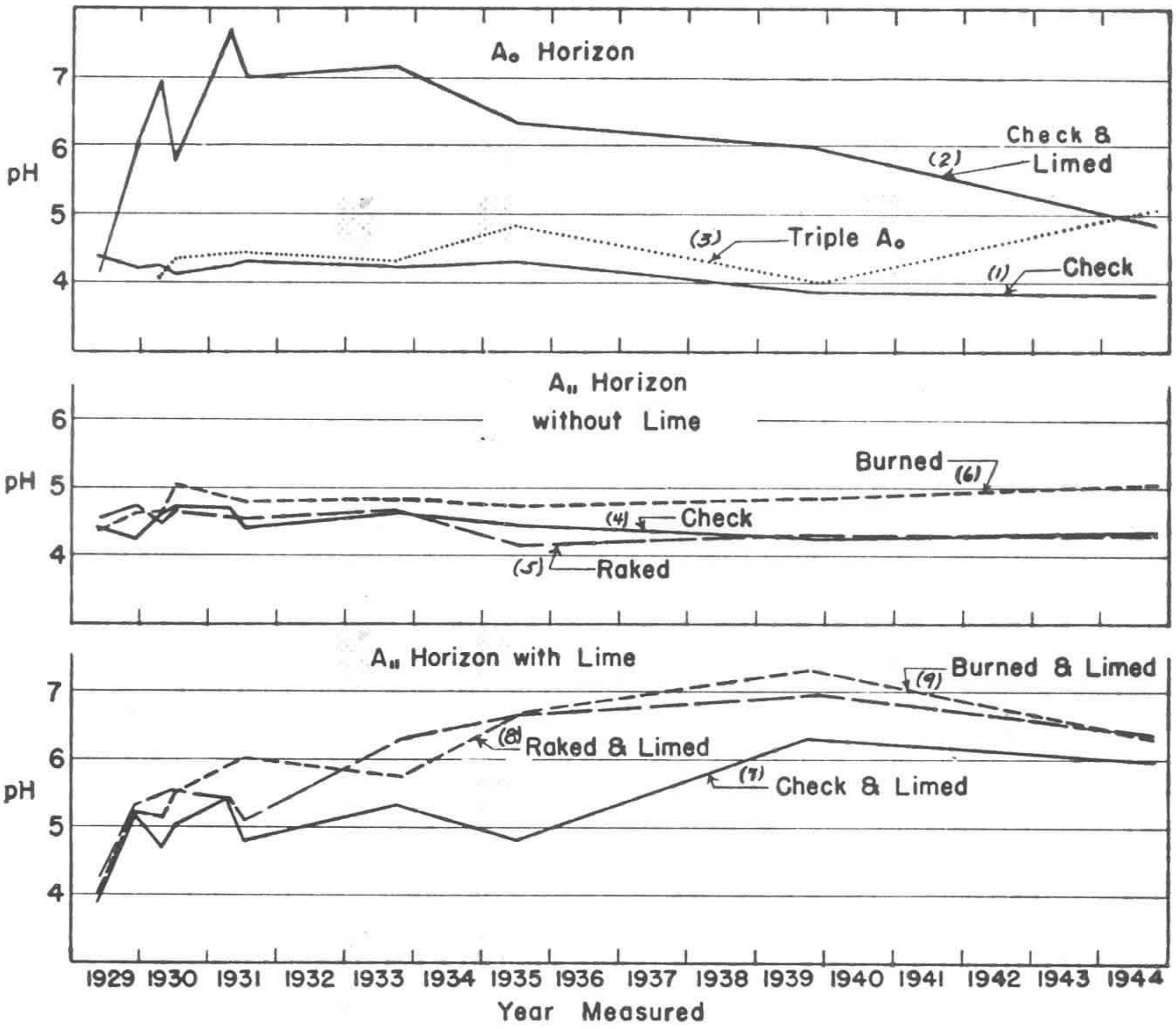

FIG. 1.—Soil reaction (pH) under red pine during the period 1929 to 1944 as influenced by the several treatments.

was maintained throughout the period. The A_{12} was affected by lime but not by burning (Table 4).

At the end of the first 10 years lime had raised the pH of the B_{21} horizon (at the 8–11 inch depth in most instances) only about 0.3 pH whether raked, burned or undisturbed. By the 14th year (see Table 4) lime had penetrated to the B_{21} horizon of the burned plot sufficiently to raise its pH from 4.5 to 5.5, but on neither of the other two treatments was there any difference whatsoever.

(e) **Ammonification and nitrification.** As the tests for ammonia and nitrates on field samples showed no significant effects from either raking or burning, the data are omitted. Liming tended to increase the amount of nitrates at the expense of ammonia, but the differences were small. This condition of low values and lack of response to treatment is due to rapid absorption of available N by tree roots, thus preventing accumulation to any extent.

When soil samples were incubated at the laboratory[12] in the absence of root competition, it was found (Table 3) that lime had a marked effect on nitrate production with a corresponding reduction in ammonia. This is in line with previous work (9) and is usually ascribed to an increased bacterial activity and a lessening of fungi action as result of the change in soil reaction and the presence of lime.

Nitrogen transformation in the A_{12} horizon was less affected by lime because of the slowness of lime penetration into the soil.

(f) **Chemical properties.** Data obtained on the 1944 samples (red pine plots only) are presented in Table 4. The effects of treatment on pH have already been discussed. Other differences as result of treatment are as follows:

Total N.—(a) The A_{11} and A_{12} horizons on the raked plots were higher in N than those on the undisturbed check plot; (b) in the top three horizons (Ao, A_{11}, A_{12}) liming appeared

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[12] The top 6 inches of soil, together with overlying Ao where present, was sampled with a 3-inch diameter cylinder and transferred as a unit without disturbance to straight-sided quart glass jars. Incubation was carried on out-of-doors on a shaded bench adjoining a building (9).

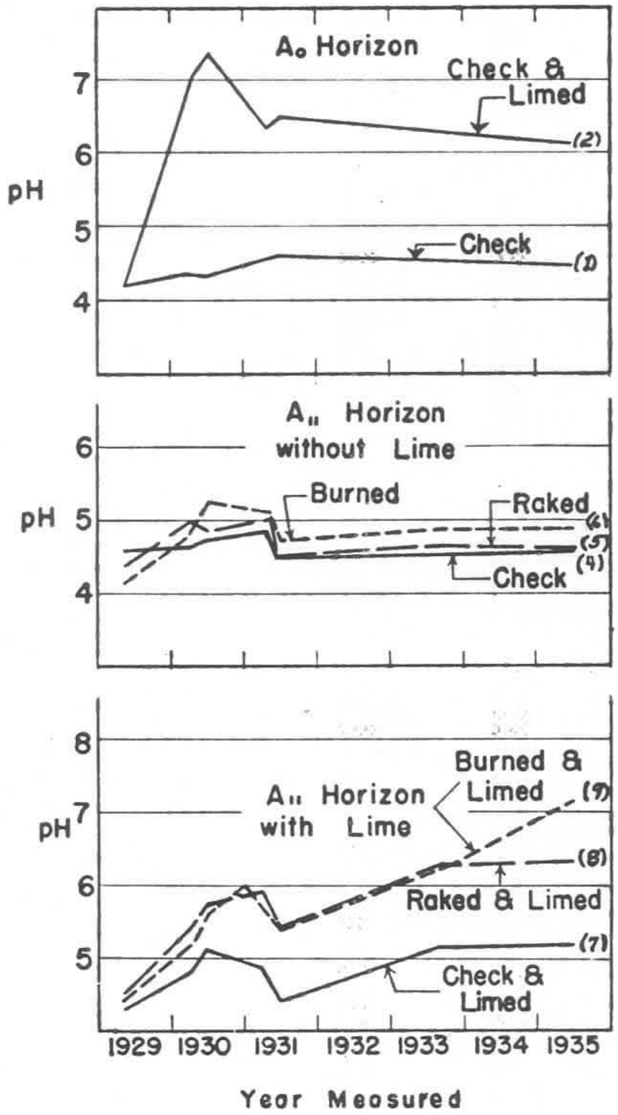

FIG. 2.—Soil reaction (pH) under white pine during the period 1929 to 1935 as influenced by the several treatments.

to be associated with a higher N content; (c) the effect of burning is not clear, but the highest value of all mineral soil samples was the A_{11} on the burned-plus-lime plot 6.

Organic carbon and loss-on-ignition.—These generally varied with the total N values. In fact the high N content of the A_{11} on plot 6 was undoubtedly due to its higher organic matter content.

C-N ratio.—The A_{11} horizon of the triple Ao treatment had the widest ratio, and the B_{21} of the same treatment the narrowest.

Available P.—(a) Phosphorus was much higher in the Ao than in the underlying mineral soil; (b) in the A_{11} it was higher in the burned plots than on either check or raked; (c) lime lowered the P content of the Ao but tended to increase it in the A_{11} except on the raked plot; (d) the treatments had no noticeable effect on the P content of the A_{12} and B_{21} horizons.

Exchangeable Ca.—(a) In the A_{11} and A_{12} raking appeared to result in a lower Ca content; (b) burning made for a marked increase in the A_{11} only; (c) liming resulted in higher values in all cases except in the B_{21} of the check plots. Percentagewise, the greatest increases were in the A_{11} horizon.

Exchangeable H.—(a) As would be expected, exchangeable H was highest in the Ao; and in the A_{11} it tended to be higher in triple Ao than in either check or raked treatments, due no doubt to a somewhat higher concentration of organic acids in the former; (b) liming obviously lowered exchangeable H markedly in the A_{11} and to a slight degree in the A_{12}.

Cation exchange capacity.—In the A_{11} and A_{12}, liming resulted in slightly higher values, but in the Ao liming appeared to have the opposite effect. No reason is known for the latter result.

EFFECT OF TREATMENT ON THE STAND

The data pertaining to diameter measurements for red pine[13] are given in Table 5. Differences in growth are slight. The lowest increase for the 19-year period was on the raked plot, but on the basis of the percentage increase over 1928 diameters the burned plot trees were identical to the raked. These findings are in general agreement with those of Kawada (8) and Jamison (7).

The triple Ao plot trees made by far the greatest increase in both periods, 1928–34, and 1934–48. Liming favored diameter growth on both the raked and the burned plots.

Total height measurements (Table 6) do not indicate any consistent effect of treatment, but growth over the 19-year period was slightly less on the raked plot, and greater on the burned and triple Ao plots as compared with the check. That liming definitely increased rate of growth is shown in the percentage increase over the initial 1928 heights (column 7). The differences in percentage increases during the last 19 years (column 7) as compared with the 5-year period preceding 1928 (column 3) lend emphasis to the treatment effects registered by these data.

Diameter and height measurements of the dominant and co-dominant trees were tabulated separately, but the values differ so slightly from the average of all trees that the former data are omitted.

On the basis of actual volume increase (Table 7, col. 5) raking appeared to be somewhat unfavorable, liming noticeably so, and burning was beneficial. When the volume initially present is taken into account, however, it is readily seen (column 6) that, compared with the check, raking had very little effect, while burning was definitely beneficial, as was liming. Greatest increase took place on the triple Ao plot.

DISCUSSION AND CONCLUSIONS

The data obtained in this study have indicated a relatively small but definite reduction in growth as a result of the annual removal of the litter, and an increase where the litter was burned. Factors undoubtedly contributing to the lesser growth on the raked plot are (a) the characteristically lower soil moisture content, and (b) the lower content of available P and exchangeable Ca. Because of the complete litter removal there was a lower supply of plant nutrients available for the roots.

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[13] Owing to the destruction of the white pine plots in 1938, growth measurements are necessarily confined to red pine.

Kawada (8) reported no significant differences in height growth due to litter removal. He did not mention volume data. Cope (3) measured the trees on two adjoining 55-year-old stands of loblolly pine, one of which had had fallen needles ("shats") removed annually for many years. He found a reduction in both height and volume growth. Trees on the raked stand were only 87% as tall and contained only 75% as much volume as the untreated trees.

Coming back to the present experiment, it is seen that when the volumes are plotted against time (Fig. 3) the rate of increase of the raked plots is appreciably less than that of the other plots. The graph indicates that if the trend in volume increase during the 1934–48 period were to continue, the raked plot would eventually show much poorer growth. By the same token the steeper lines representing triple Ao and lime treatments indicate a more rapid growth for those treatments.

TABLE 4.—*Chemical properties of the soil on the red pine plots as affected by treatment (1944 data).*

Horizon*	Check	Ck+L	Raked	R+L	Burned	B+L	3×Ao
		pH					
Ao	3.85	4.86	—	—	—	—	5.08
A_{11}	4.36	5.99	4.34	6.37	5.06	6.34	4.10
A_{12}	4.53	5.28	4.48	5.56	4.45	6.82	4.44
B_{21}	4.52	4.48	4.84	4.81	4.53	5.54	4.68
		Total Nitrogen, %					
Ao	0.851	1.076	—	—	—	—	0.99
A_{11}	0.069	0.075	0.091	0.086	0.100	0.120	0.079
A_{12}	0.044	0.056	0.053	0.064	0.049	0.041	0.057
B_{21}	0.028	0.030	0.033	0.030	0.028	0.027	0.037
		Organic Carbon, %					
Ao	—	—	—	—	—	—	—
A_{11}	1.37	1.67	1.98	2.03	2.01	2.57	2.33
A_{12}	1.16	1.27	1.32	1.24	0.95	1.14	1.40
B_{21}	0.57	0.49	0.49	0.47	0.43	0.57	0.51
		Carbon–Nitrogen Ratio					
Ao	—	—	—	—	—	—	—
A_{11}	19.9	22.1	21.9	23.5	20.1	21.4	29.4
A_{12}	26.5	22.5	24.7	19.3	19.3	28.1	24.6
B_{21}	20.0	16.3	14.6	16.0	15.3	21.1	13.8
		Loss on Ignition, %					
Ao	59.56	45.43	—	—	—	—	65.42
A_{11}	2.93	3.48	3.75	3.76	3.66	5.41	4.43
A_{12}	2.43	2.71	2.77	2.71	2.04	2.59	2.85
B_{21}	1.35	1.41	1.51	1.58	1.39	1.50	1.50
		Available Phosphorus, ppm					
Ao	115	74	—	—	—	—	134
A_{11}	14	20	10	10	30	93	13
A_{12}	10	11	9	8	7	11	10
B_{21}	9	8	8	6	9	11	10
		Exchangeable Calcium, Mg. eq. per 100 g Soil					
Ao	11.25	37.60	—	—	—	—	10.95
A_{11}	0.19	5.68	0.02	5.90	1.50	14.10	0.57
A_{12}	0.07	1.06	1.01	1.77	0.05	1.25	0.13
B_{21}	0.01	0.01	0.01	0.17	0.03	0.25	0.05
		Exchangeable Hydrogen Mg. eq. per 100 g Soil					
Ao	39.50	20.88	—	—	—	—	31.00
A_{11}	4.47	2.14	5.04	1.78	4.40	1.24	6.54
A_{12}	3.10	3.00	3.44	2.55	2.61	2.09	3.89
B_{21}	1.84	2.09	1.85	1.72	1.79	1.66	1.68
		Cation Exchange Capacity Mg. eq. per 100 g Soil					
Ao	54.54	39.80	—	—	—	—	54.62
A_{11}	5.76	7.23	6.79	7.20	7.15	9.47	8.62
A_{12}	4.27	4.57	4.11	5.23	3.32	4.19	5.42
B_{21}	2.64	2.31	2.44	2.40	2.61	2.43	2.47

* Horizon depths: Ao—about 2 inches; A_{11}—0–1 inch ±; A_{12}—1–8 inches ±; B_{21}—8–11 inches ±.

TABLE 5.—*Effect of treatments on the diameter of red pine. Average diameter at breast height (d.b.h.) in inches, at end of growing season for the year indicated.*

Treatment	1928 Av.	1934 Av.	1947 Av.	Gain 1928–47	Gain 1928–47 in per cent of 1928 dbh
Check	4.00	4.45	5.46	1.46	36.5
Ck+L	3.80	4.20	5.20	1.40	36.8
Raked	4.00	4.40	5.30	1.30	32.5
R+L	3.70	4.00	5.10	1.40	37.8
Burned	4.30	4.80	5.70	1.40	32.5
B+L	4.00	4.40	5.40	1.40	35.0
3×Ao	3.80	4.40	5.69	1.89	49.7

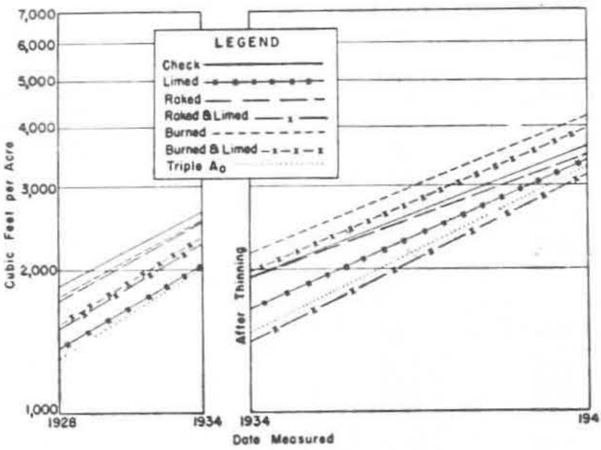

FIG. 3.—Tree volumes in cubic feet per acre in 1928, 1934 (both before and after thinning), and 1947. Red pine. The steepness of the lines is indicative of the changes in growth rate.

Associated with the beneficial effect of burning are the higher values in the top soil for pH, total N, available P, and exchangeable Ca. These effects are seemingly independent of the loss of nitrogen and organic matter in the unincorporated litter. Wahlenberg (16) found that although burning had an unfavorable effect on soil structure and permeability, it resulted in a higher content of available N, exchangeable Ca, and organic matter. In greenhouse tests, slash pine grew better on burned soils. Finn (4) found an increase in leaching of NO_3-N, Ca, and K as a result of burning. Alway and Rost (1) reported that burning the leaf mold on sandy soils made nutrients more available and increased production of the soil the first year at the expense of subsequent years. Their interest was chiefly in the use of the land for agriculture.

The recent work of Burns (2) on the New Jersey pine barrens substantiates much of what has been reported elsewhere. He found that while the mineral soil is benefitted chemically by annual burning over long periods of time, such treatment has "ecologically unfavorable effects on the forest floor". Moderate burning (once in 2 to 4 years), on the other hand, appeared to be ecologically favorable.

A pot culture experiment at this Station (11) with undisturbed soil from under hardwoods and seeded to spruce has shown that removing the Ao, or burning it off, or mixing it into the soil resulted in an increase in the amount of available nutrients, total N, and organic matter that was removed when the pots were leached with water. Although survival of spruce seedlings was better where the Ao was removed by raking or burning, growth was definitely poorer as a result of such treatment.

Artificially increasing the amount of forest floor (triple Ao treatment) resulted in a quite pronounced stimulation in tree growth. One of the most important factors here is the larger supply of nutrients occasioned by the much greater quantity of litter present,—a situation similar to that obtained when a thick mulch of straw or hay is placed in an orchard. It was shown that an estimated 8,000 pounds of litter decomposed annually on the triple Ao plot as compared with 3,300 for the normal undisturbed plots. Since the percentage composition of this triple Ao layer was generally equal to or slightly higher than that of the normal litter, the amount of liberated plant nutrients should be considerable. The fact that this assumed increase does not show up in the underlying soil to the degree expected is undoubtedly due to the rapid assimilation of the nutrients by the tree roots.

Finally there is the rather pronounced benefit of liming to consider. Earlier work (10) has indicated that red pine transplants are unfavorably influenced by lime treatment. It is possible that young trees respond somewhat differently than do older ones. A more likely explanation, however, is the generally higher pH level of the soil in the previous work as compared with that at the Rainbow Plantation. A moderate increase in pH and in available calcium from a rather low level is likely to result in a favorable growth response, whereas at a higher level the use of lime will have no benefit.

Inspection of soil data shows first, that liming seems to have resulted in a higher soil moisture content, particularly under the red pines. Possibly this was due to the slightly higher organic carbon and loss-on-ignition values, but just how liming can result in these higher values is not known. Heyward and Barnette (5) theorized that in their situation burning resulted in more grass, and it was the decaying grass roots that brought up the N and organic matter content. However, there was no grass in the plantation blocks under consideration.

Aside from moisture and organic matter, the limed plot soils tended to be slightly higher in N, available P, and base capacity and, of course, markedly higher in exchangeable Ca, with a moderate lowering of the exchangeable H content. Another factor not to be ignored is the composition of the needles and resulting litter. The litter from limed trees, both red and white pine, contained about 67% more Ca than that from unlimed trees. Unfortunately, no comparable analyses were made of needles from all of the treatments. Némec (13) reported that needles produced on raked plots were definitely higher in ash, Ca, and K, and lower in P, Na, Mg, cellulose, and N than were those produced on undisturbed plots.

It is to be concluded that, under the conditions which existed in the Rainbow Plantation, raking the litter annually had a small but definite detrimental effect on certain properties of the soil and on tree growth. On the other hand such treatments as liming, burning, or the artificial building up of the depth of litter all had a favorable effect on certain aspects of the soil, which was reflected in increased tree growth.

What the long time effects of annual burning would be on the stand can only be surmised. In terms of 50 years or more, it would seem that the continued losses of nitrogen and organic matter, and the deterioration in physical condition of the soil occasioned by such treatment, would ultimately slow down growth and affect the character of the stand.

SUMMARY

On a series of six 1/40-acre plots in a red pine plantation on Merrimac loamy sand, the annual litter removal by raking was compared over a period of 19 years with annual litter burning and with undisturbed litter,

TABLE 6.—*Effect of treatments on heights of red pine. Average total height in feet at end of growing season of year indicated.*

Treatments	1923* Av.	1928 Av.	Gain 1923–28 in per cent of 1923 ht.	1934 Av.	1947 Av.	Gain 1928–47	Gain 1928–47 in per cent of 1928 ht.
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Check	21.5	26.5	23.3	31.7	40.5	14.0	52.8
Ck+L	19.9	24.4	22.6	29.7	38.9	14.5	59.4
Raked	20.8	25.9	24.5	30.7	39.3	13.4	51.7
R+L	18.6	23.3	25.3	28.3	38.9	15.6	66.9
Burned	21.9	26.3	20.1	31.7	41.3	15.0	57.0
B+L	20.3	24.3	19.7	29.9	39.6	15.3	63.0
3×Ao	19.3	24.0	24.3	29.9	39.5	15.5	64.6

* Obtained in 1928 by measuring back 5 whorls.

TABLE 7.—*Effect of treatments on volume of wood on red pine plots, in cubic feet per acre. Measurements as of end of growing season of year indicated.*

Treatments	1928	1947	Gain	Removed in 1934	Total gain	Gain in per cent of 1928 vol.
	(1)	(2)	(3)	(4)	(5)	(6)
Check	1,852	3,625	1.773	750	2,523	136.2
Ck+L	1,510	3,353	1.843	620	2,463	163.1
Raked	1,730	3,470	1.740	610	2,350	135.8
R+L	1,372	3,126	1.754	636	2,390	174.2
Burned	1,759	4,200	2,441	405	2,846	161.8
B+L	1,536	3,906	2.370	373	2,743	178.6
3×Ao	1,296	3,292	1.996	572	2,568	198.1

with and without liming. A similar series under white pine was destroyed by the 1938 hurricane after 9 years of treatment. On a seventh red pine plot the natural forest floor was supplemented with litter from the two red pine raked plots.

The initial forest floor under red pine averaged 27,800 pounds per acre, and the annual needle fall 3,555 pounds. Final measurements indicated an average yearly gain of 212 to 258 pounds for the normal undisturbed plots and an annual decomposition rate of about 3,300 pounds per acre. Comparable figures for the triple Ao plot are 1,722 pounds annual accumulation and 7,927 pounds annually decomposed.

Under white pine the initial forest floor averaged lower, 21,539 per acre, and the annual needle fall was 21% higher than red pine for the comparable period of measurement (1934–37).

White pine litter analyzed higher in ash, total N, available P, and SiO_2 than red pine, and in both species liming greatly increased exchangeable Ca. The effects of soil treatments on various characteristics are discussed briefly.

Tree measurements of the red pines at the start (fall season of 1928) and in 1934 and 1948 (end of 1947 season) show relatively small differences in d.b.h. and total height, with somewhat better defined differences in tree volume. Greatest differences are shown when the growth is considered in relation to the original measurements. Raking had a slightly unfavorable effect on growth due, probably, to lower soil moisture and the lower content of available P and Ca, and the almost complete removal of the surface supply of plant nutrients.

Burning favored both height growth (8.1% more than the check in relation to the original heights) and volume growth (18.8% more than the check), as the result, probably of the higher values in the top soil for pH, total N, and available P and Ca, and possibly other unknown benefits.

Best growth was obtained on the triple Ao plot (22.3% more height and 49.8% more volume than the check) due chiefly to the greatly augmented supply of plant nutrients released by the estimated 8,000 pounds of litter decomposed annually.

Liming favorably influenced growth when considered in relation to the initial tree size (10 to 29% more than the comparable unlimed plots), and was associated with higher soil moisture content and a slightly higher level of N, available P, and base capacity, and a much higher exchangeable Ca content.

The work indicates that under the conditions of the investigation, raking had a small but definite detrimental effect on certain properties of the soil and on tree growth. On the other hand burning, liming, and the application of additional litter all had a favorable effect on certain aspects of the soil and upon tree growth. It is believed, however, that annual burning, if continued over a long period of time, would ultimately have an adverse effect on stand growth and character.

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